Geosciences Provide a Foundation for Sustainable Water Management

Climate change and pollution are intensifying global water scarcity, making the responsible management of water resources more critical than ever. Hydrogeology – an essential branch of geoscience – plays a vital role in ensuring safe drinking water, sustainable groundwater use, and responsible industrial water practices. By integrating hydrogeological expertise into decision-making, we can better address contamination risks, mitigate climate impacts, and meet the growing global demand for clean water.

Sustainable management and protection of water resources relies on a deep understanding of our groundwater systems

Comprehensive geoscientific understanding plays a pivotal role in developing solutions with advanced modelling, innovative monitoring techniques, interdisciplinary research, and capacity building. It ensures sustainable water management whilst addressing natural and anthropogenic contamination risks, climate impacts, and the growing global and industrial demand for clean water. In the extractive industry, responsible water management is also needed to decrease the environmental footprint of the activities.

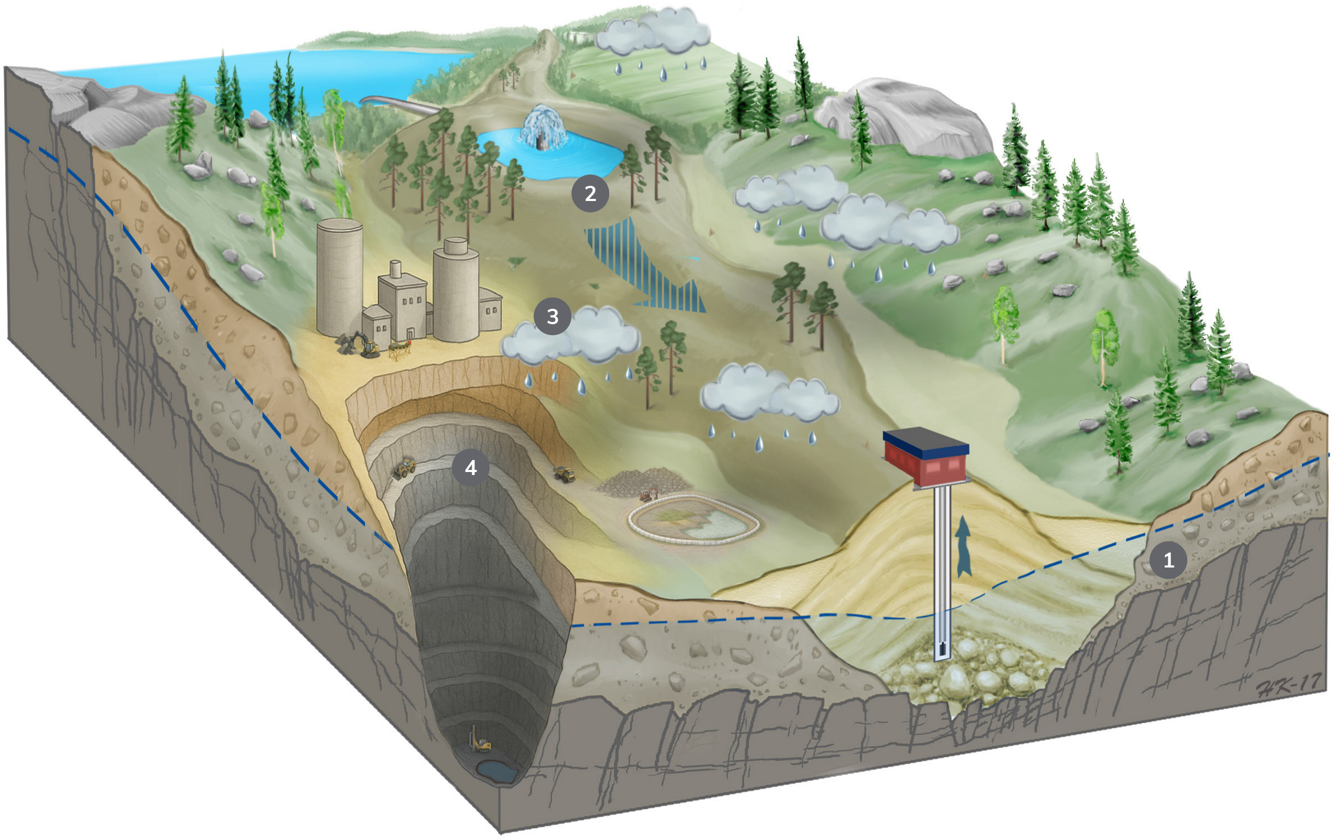
GTK's activities focus specifically on:

- Hydrogeological modelling of local and regional groundwater systems to address climate-induced challenges in water supply, recharge, and quality.
- Providing geoscientific expertise in developing management solutions for aquifer systems and tools to increase understanding and prevention of groundwater contamination.
- 3D understanding of hydrogeochemical processes and pathways of natural and anthropogenic contaminants, such as arsenic (As), radon (Rn), PFAS, and microplastics.
- Sustainable water management throughout the life cycle of mining projects with comprehensive understanding of long-term behaviour of extractive waste, regional hydrogeological setting, and overall water balance.

Hydrogeological research provides critical data on groundwater recharge, flow, and interactions with surface water, offering actionable insights for sustainable practices in natural and urban environments. This expertise is vital in addressing challenges related to global climate and environmental change.

GTK research presented in this Policy Brief contributes to these United Nations Sustainable Development Goals

3 GOOD HEALTH AND WELL-BEING | 6 CLEAN WATER AND SANITATION | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | 11 SUSTAINABLE CITIES AND COMMUNITIES | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | 13 CLIMATE ACTION | 17 PARTNERSHIPS FOR THE GOALS



Geoscientific insights into water challenges

Ongoing climate change impacts groundwater recharge and hydrological cycles globally, but especially in our Arctic and sub-Arctic regions. Anthropogenic contaminants such as PFAS and microplastics threaten water quality. Natural geogenic contaminants and mining operations add complexity, requiring geological understanding and geoscientific solutions for environmental risk management and sustainable water management. Science-based knowledge and integrated solutions provide the foundation for sustainable water management with geological 3D modelling and hydrogeological flow modelling, AI-driven spatial data analysis, and interdisciplinary research and collaboration.

Understanding groundwater dynamics (1)

Geoscientific data and methods are crucial for understanding changes in groundwater resources, groundwater recharge and flow patterns under changing climate scenarios in the Arctic and sub-Arctic regions. With the network of hydrogeological test sites established in 2024, GTK can support the research on hydrogeology and global change (see infobox on HYGLO WOLL).

Regional hydrogeological modelling integrates groundwater flow with surface water and the carbon cycle, advancing climate-responsive water management.

Managed Aquifer Recharge (MAR) (2)

Managed Aquifer Recharge (MAR) refers to increasing the groundwater recharge artificially by infiltrating surface water or collecting water during the rainy season and recharging the groundwater reserve in a controlled manner.

As climate change increases extreme weather events, MAR solutions are crucial worldwide to manage droughts, floods, and seasonal variations, ensuring a stable and sustainable water supply. Studies on aquifer geology and hydrochemistry ensure environmentally sound MAR practices.

Contamination risk mitigation (3)

Geoscience-driven spatial assessment, as well as an understanding of hydrogeochemical processes and pathways and of natural and anthropogenic contaminants, such as arsenic (As), radon (Rn), PFAS, and microplastics, coordinate effective mitigation strategies for the safe use of groundwater.

Hydrogeological modelling tools enhance delineation of groundwater vulnerability zones, supporting risk reduction and water safety.

Responsible mining and water (4)

Hydrogeological and geochemical research enable comprehensive understanding of environmental risks to water systems associated with mining operations and the disposal of extractive waste, supporting both sustainable operational and post-closure water use and management, waste management, and the prevention of environmental impacts (see infobox on GTK SMARTTEST).

Predictive modelling of water-related impacts in mining, systematic conceptualization of hydrogeological settings in mining areas, field testing of waste management options, and development of remote sensing and AI applications help to reduce the environmental footprint of mining and to revolutionise monitoring and the remediation of mining sites.

Guidance and capacity building

Guides and statements on mining environments direct national legislation into practice. National and international capacity building deploys geoscientific information -based expertise to support water supply and its various solutions, such as MAR, in a changing climate and environment.

Geoscience-driven water resource management prepares for the future

By anchoring water resource management in geoscientific knowledge, we can prepare for critical environmental water challenges, ensuring sustainable solutions for future generations.

Enhance water resilience. Expand groundwater research networks to collect data on recharge, flow, and climate impacts, especially in Arctic and sub-Arctic environments, to guide water resource planning in a changing climate.

Prepare for the unexpected. Identify alternative water resources less vulnerable to sudden contamination due to, for example longer residence times (e.g. bedrock wells).

Integrate hydrogeological expertise. Enhance geological research on surface and groundwater contamination transport and mitigation, including natural and emerging anthropogenic contaminants (such as As, PFAS, micro and nano plastics, process chemicals).

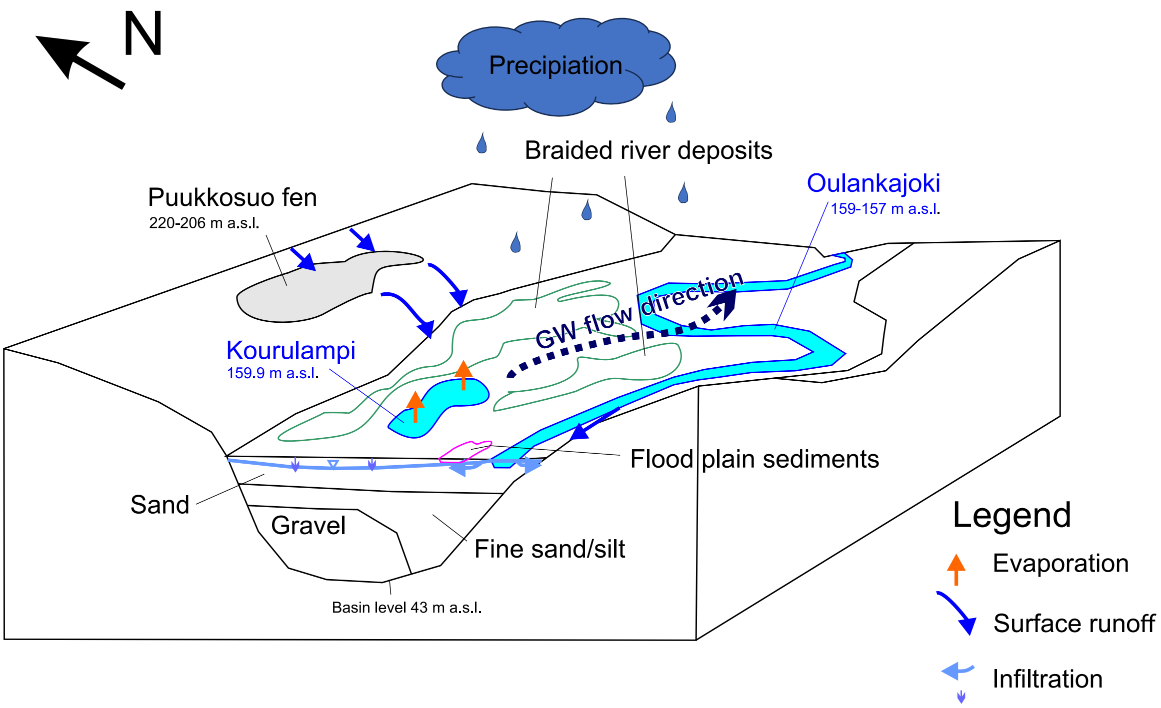
Minimise environmental impacts. Use a holistic approach, geoscience-based understanding, and long-term testing to reduce the environmental footprint of industrial activities on water resources and improve their sustainability.

Improve predictability for decision making. Apply existing geodata and geoscience-based modelling, geophysical methods, and AI-driven approaches to improve industrial water and waste management, site remediation, and decision-making in water safety.

Collaborate across sectors. Support sustainable groundwater management and responsible mining by capacity building and fostering partnerships between geoscience experts, stakeholders in water management and industrial operations, the authorities, and decision- and policymakers.

Invest in new innovations and capacity building. Strengthen and generate multidisciplinary expertise to develop water sector solutions. National optimisation and water management solutions will support international capacity building actions as well.

HYGLO WOLL provides real life test sites for groundwater management



The hydrogeological conceptual model of the HYGLO WOLL Oulanka test site. The test sites enable conceptual understanding, but also comprehensive numerical modelling of the subsurface groundwater flow in 3D.

GTK has established 10 hydrogeological test sites in diverse geological environments across Finland. These test sites (HYGLO WOLL) belong to the international network of Water Europe Water Oriented Living Labs (WOLL).

WOLLs are defined as "user-centered, open innovation ecosystems based on a systematic user co-creation approach in public-private-people partnerships, integrating research and innovation processes in real-life communities and settings".

HYGLO WOLL supports the research related to development of groundwater recharge, management of water resources, groundwater-surface water interaction, managed aquifer recharge, the role of groundwater in the carbon cycle, the sedimentary aquifer-bedrock aquifer interface, and mining environments.

- Serves as a research platform for testing monitoring devices and studying phenomena related to climate change; such as flooding, draughts, extreme events, changes in snow cover, and groundwater recharge.
- Provides near real-time water quality and quantity monitoring data and facilitates research to enhance understanding of the development of groundwater resources in sub-Arctic and Arctic areas in changing climate and land use activities.
- Offers case study sites for national and international research collaboration projects.

GTK maintains the HYGLO WOLL sites and establishes agreements with local partners, including water companies, other companies, municipalities, universities and their research stations, research institutes, governmental agencies, and local associations. Together with existing and future partners and collaborators, GTK will actively develop HYGLO WOLL.

More information

GTK SMARTTEST – Long-term behaviour and management of extractive waste and side streams to support sustainable water management in the extractive industry

Management of extractive waste and prevention of water contamination at mine sites requires reliable data on the long-term behaviour of waste materials and performance of their management and closure solutions. Such data have traditionally been produced at the laboratory scale. Recently, field tests have been developed to better simulate the behaviour of wastes and their management under local climatic conditions. Field tests improve the scalability of test results to the operational scale.

The newly introduced GTK SMARTTEST is a customisable and modular field-testing concept for tailings, waste rocks, and side streams. It promotes the circular economy and responsible management of extractive waste, side streams, and waters in the extractive industry.

GTK SMARTTEST provides:

- Innovative solutions for the management of extractive wastes to reduce environmental impacts, especially effluents and impacts to waters during the mine life cycle.
- Resource efficiency and enhances circular economy by optimising the use of waste materials and developing solutions to increase the use of mineral side streams in the extractive industry.
- Real-time data on geochemical and geotechnical insights for waste and related water management.
- Research on long-term behaviour and effluent quality of extractive waste as well as various management and closure techniques, such as cover structures and novel disposal methods (dry stacking, paste disposal, co-disposal).

More information

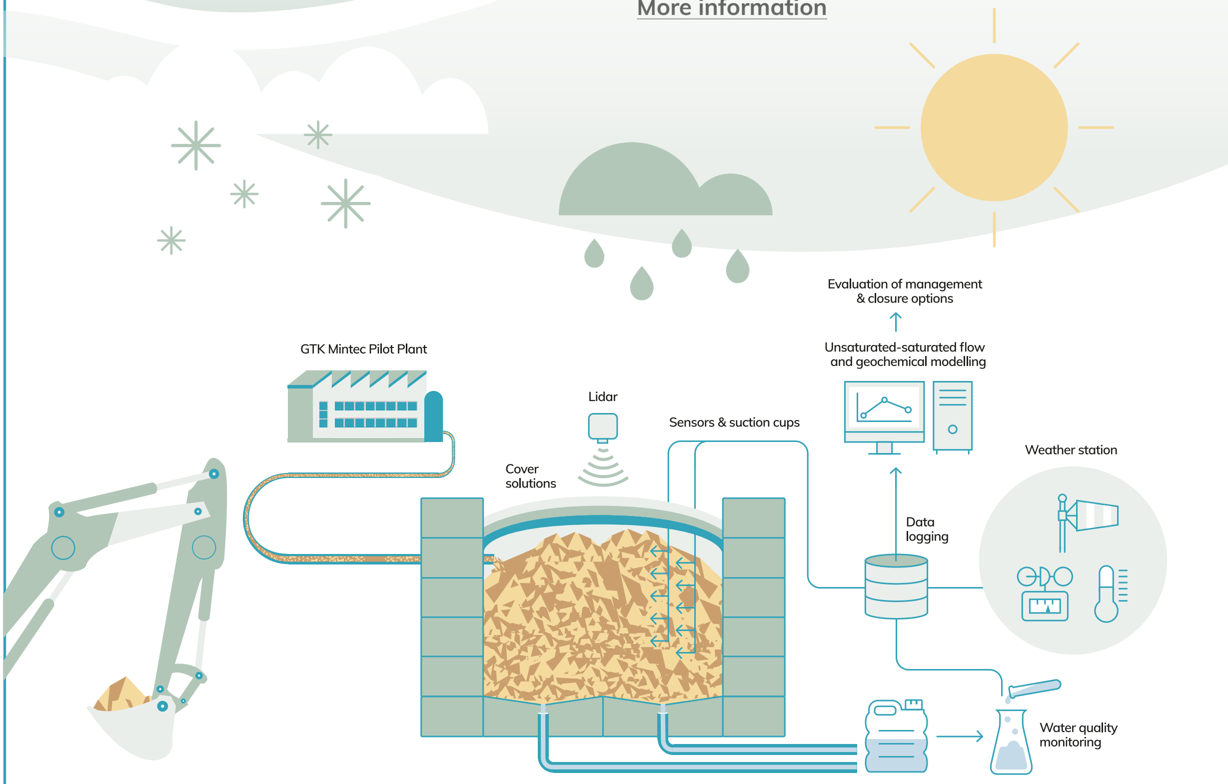


Diagram shows how the GTK SMARTTEST test field functions. After mineral processing test in the GTK Mintec pilot plant, field tests can be carried out to evaluate long-term behavior and management options for the extractive wastes generated during piloting. Extractive waste for the field tests can also be transported from mine sites. The tests can also be used to study utilization of other side streams in extractive waste management. Test structures are constructed of concrete blocks and the performance of the studied management techniques are monitored using various sensors, lidar technique, and by analyzing quality and quantity of seepage and pore waters as well as surface drainage. Weather station is used to follow weather conditions at the test site. Data from sensors is collected to online cloud service, and geochemical modelling is used to interpret and scale-up the test results to the operational level.

Sources and additional information

GTK's research areas, policy briefs and research projects

Sustainable Water Resources – information and research projects

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GTK research news

- The Deep Groundwater Project in Kurikka Proceeds to the Next Phase Where the Water Extraction Volume Will Be Examined by Test Pumping and Modelling
- The Research Council of Finland Is Providing Funding for GTK for Groundwater and Surface Water Research
- Significance of Clean Water as a Critical Resource Grows – Managed Aquifer Recharge Improves the Security and Sustainability of Water Supply
- Smart Field-Testing Platform and Concept Improves Management of the Long-Term Behaviour of Extractive Waste
- Groundwater Resource Management under the "New Normal" of Climate Change – Challenges and Perspectives from Finnish Cases
- Initially Challenged by the Coronavirus Pandemic, the NeAs Project Is Now in Full Swing, Looking for Solutions for Arsenic in Drinking Water in Nepal

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The Geological Survey of Finland (GTK) produces impartial and objective research data and services in support of decision-making in industry, academia, and wider society to accelerate the transition to a sustainable, carbon-neutral world. GTK employs more than 400 experts specializing in the mineral economy, circular economy, solutions related to energy, water and the environment, as well as digital solutions. GTK is a research institution governed by the Finnish Ministry of Employment and the Economy, operating in Finland and globally.